

Contact: Louise Lerner
(630) 252-5526
Louise@anl.gov
May 4, 2011

Combining gas and diesel engines could yield best of both worlds

It may be hard to believe, but the beloved gasoline engine that powers more than 200 million cars across America every day didn't get its status because it's the most efficient engine. Diesel engines can be more than twice as efficient, but they spew soot and pollutants into the air.

Could researchers at the U.S. Department of Energy's Argonne National Laboratory engineer a union between the two—combining the best of both?

Steve Ciatti, a mechanical engineer at Argonne, is heading a team to explore the possibilities of a gasoline-diesel engine. The result, so far, is cleaner than a diesel engine and almost twice as efficient as a typical gasoline-powered engine.

The basic designs for both kinds of engines actually date back to the 19th century. German engineer Nikolaus Otto is credited with the gasoline-fueled four-stroke design still used today, but Rudolf Diesel noticed the inefficiency of the engine and came up with a design of his own in 1893. The problem is that while diesel engines are more efficient, their emissions are noxious—full of soot and smog-forming nitrogen oxides, or NO_x gases. Gasoline engines are cleaner, but a typical gas engine is only about 20 percent efficient—that is, only 20 percent of the energy in the fuel actually moves the car, while 80 percent is lost to friction, noise, engine functions or goes out as heat in the exhaust. Many diesel engines reach 40 percent efficiency and higher.

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Gas-diesel hybrids—add one

Today the United States has more stringent emissions requirements than anywhere else in the world. "In fact, as of 2007, in some parts of the country the air coming out of a car is cleaner than the air that went in," Ciatti said, and engineers haven't been able to get diesel emissions low enough to meet those standards.

Ciatti and colleagues wanted to clean up diesel's dirty exhaust, but keep the high efficiency and better gas mileage. To do this, they headed to the dynamometer lab at Argonne's Transportation Technology R&D Center.

The dynamometer is a machine built to test engine performance. Essentially, it's just an electric motor to provide resistance to fool the engine into thinking it has a car attached. Dynamometer test cells can be heavily instrumented and accurately controlled, significantly improving data quality.

"If you're trying to test out a new engine, the last thing you want to do is put it in a car," Ciatti explained. "An entire car system introduces all sorts of variables, and you can't get a truly accurate comparison between engines. What you really want to start with is a dynamometer."

Combine a dynamometer with the engine you're testing, and you have an engine test cell: an arrangement that lets you control the tiniest variables, so that engineers can tinker with the engine to see if they can improve its performance. They can simulate how an engine would perform in different cars—a hybrid car, an electric car, a gas-powered car—and can also measure emissions.

With a diesel engine installed in the test cell, Ciatti and his team were ready to explore the possibilities.

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How a car works

In a typical engine, pistons turn the wheels of the car. Each piston is moved by the explosive force of hot air when fuel is ignited in a cylinder.

Both spark-ignited gas engines and diesel engines do this, but they go about it differently. A gasoline engine first mixes air with the fuel, then compresses the mixture, and finally ignites it with a spark plug. In a diesel engine, the air is *first* compressed and *then* the fuel is injected; compressing the air makes it hot enough to ignite the fuel without a spark. This is what makes diesel more efficient—and also dirtier.

On one hand, diesel engines are more efficient because they do not control power with a throttle, which restricts air to the chamber. This means the fuel mixes more evenly with air, so more of it burns. Lack of a throttle also eliminates "engine knock" —caused by fuel igniting prematurely in the engine—because fuel is introduced only in the combustion chamber.

On the other hand, the introduction of fuel so late in the cycle creates a problem: emissions. Since fuel burns more easily when the droplets are smaller, the fuel is sprayed into the chamber as a fine mist. But diesel fuel is so easy to auto-ignite that it begins to react almost immediately—long before all of the fuel is in the chamber. Intentionally, the fuel isn't mixed perfectly with the air because diffusion controls the combustion; but diffusion also means some air and fuel are converted into soot and nitrous oxides.

Nitrous oxides are created when the flame jet created by the diesel injection burns so hot that nearby nitrogen and oxygen molecules in the air start to break apart and react. Meanwhile, soot is created inside the hot jet because the fuel doesn't have enough oxygen to fully burn, creating soot instead.

Gas-diesel hybrids—add three

"What we want to do is combine the efficiency of diesel with the cleanliness of gas," Ciatti said. "So we lose the throttle and spark plugs, because those create inefficiencies. We start with a diesel engine and inject gasoline instead. Because gasoline doesn't ignite immediately the way that diesel would, we can actually inject several times before the fuel ignites. That way, we can make sure that the most or all of the fuel is mixed with the air, significantly decreasing NO_x and soot."

The engine's performance is close to diesel efficiency and roughly double that of today's automotive engines at low speeds and loads.

What's the catch? This approach results in better efficiency and cleaner emissions, but sacrifices some of the power density. That is, at peak power—when you push the accelerator pedal to the floor—the engine won't provide quite as much power: about 75 percent at present.

"But if you don't drive pedal to the metal," Ciatti said, "this won't affect the car's performance. It's excellent in the power range where most people actually drive."

Ciatti and his colleagues are working to make the system predictable and reliable enough to be successful in a commercial vehicle. Argonne is collaborating with General Motors on this project.

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